2004 Annual Project Summary
Active Deformation and Earthquake Potential of the Southern Los Angeles Basin, Orange County, California

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Investigations Undertaken

We have been investigating whether active compressional tectonics extend as far south as Orange County, where strike-slip tectonics of the Peninsular Ranges and Borderland intersect the southern LA Basin approximately 65 km south of the Transverse Ranges. These investigations indicate that the San Joaquin Hills (SJH), Puente Hills (PH) and Santa Ana Mountains (SAM) are actively uplifting geologic structures, that they are not fully integrated into regional tectonic models, and that the seismic hazard of Orange County needs to be reassessed.

A summary of our work in 2004 is presented in two companion reports. The first report for award 03HQGR0062 describes the goals of the entire project and our activities in sample collection and geomorphic analysis during a no-cost extension of the 2003 award. This report describes our activities under the 2004 award.

The proposed work for project year 2004 has not been completed because results are still pending for 7 OSL (optically stimulated luminescence) dates of terrace deposits. In 2003 we collected 7 samples from uplifted fluvial terraces along Santiago Creek in the Santa Ana Mountains, and on the north side of the Santa Ana River canyon in the Puente Hills. Ages of 6 samples and preliminary uplift rates derived from them are reproduced in Table 1 below. One sample was destroyed in a laboratory accident. In 2004 we collected 7 additional samples for dating. Results are expected in early 2005. We intend to request a no-cost extension of project year 2004 funds so that we can finish geomorphic analysis and write up results after the second batch of samples has been dated with OSL. The results section of this report summarizes several working hypotheses and preliminary interpretations of the neotectonic development of the southern Los Angeles basin, Orange County, California, popularly known as “The OC”.

Results

Full results will be presented in at least 2 manuscripts, Final Technical Reports, and Eldon Gath’s dissertation. One manuscript will describe the neotectonic development and geomorphic evolution of the southern Los Angeles basin. Another manuscript will focus on tectonic geomorphology of the Puente Hills and Santa Ana mountains.

To check the results of geomorphic analysis and terrace age correlations (see companion report 03HQGR0062), we are measuring uplift rates directly by dating the youngest terraces in the Santa Ana Mountains, and on the southern flank of the Puente Hills in Santa Ana River canyon. *Initial* results and uplift rates are shown in **Table 1**.

Table 1 – Preliminary uplift rates derived from terraces

Sample	**LG1**	**LG2**	**LG3**	**LG4**	**LG6**	**LG7**
Age (ka)	61.4	58.5	51.5	> 75	31.9	38.0
Error (ka)	6.9	7.3	5.4		4.8	3.9
D. Elev (m)	21	21	21	15	38	36
Uplift (m/ka)	**0.34**	**0.36**	**0.41**	**$\leq$ 0.2**	**1.19**	**0.95**
Terrace	Qt2	Qt2	Qt2	Qt1	Qt1	Qt2
Location	Irvine Lake, SAM*	Irvine Lake, SAM*	Irvine Lake, SAM*	Peralta Pt.	SAR PH**	SAR PH

*Santa Ana Mountains
**Santa Ana River, Puente Hills

PUENTE HILLS

The Puente Hills are comprised of anticlinally deformed Miocene rocks. The right-lateral Whittier fault cuts across and offsets the southern foothills. All of the southwesterly flowing streams in the Puente Hills are right-laterally deformed where they cross the Whittier fault. Immediately south of the Puente Hills lie the Coyote Hills, an en echelon sub-parallel series of anticlines. Uplift of the Puente and Coyote Hills has recently been attributed to a blind thrust underlying both sets of hills. This thrust, the Puente Hills fault, was the cause of the 1987 Whittier earthquake (Shaw and Shearer, 1999).

The Puente Hills anticline is asymmetric with the southern flank approximately 3 times longer than the northern. A linear, consequent drainage network has developed on the southern flank. The four largest drainage basins are La Mirada, Brea, Tonner, and Carbon canyons, from west to east. The main stream channel of all four basins has been right-laterally offset 1700±100 meters by the Whittier fault. Intermediate to these four principal basins are several smaller drainage basins. The channels of these smaller basins are also offset by the Whittier fault, but they are offset smaller distances, between 400 and 1100 meters.

Using the 2-3 mm/yr Holocene slip rate measured by Rockwell and Gath (in prep), retrodeforming the channel offsets yields the age of the channel initiation. The principal canyons (La Mirada, Brea, Tonner, and Carbon), each offset 1700 meters, are therefore 570-850 ka. The 400-meter offset channels are 130-200 ka, and the smaller offset channels are even younger.

Four elevated Santa Ana River terraces are preserved on the Puente Hills side of the river through Santa Ana Canyon (see companion report). These fill terraces are dominated by coarse, clastic deposits, with occasional lenses and strata of sand. We collected samples of the sand for OSL age dating (Figure 1). While yielding consistent results (Table 1) between samples from the same terraces, all of the results were approximately half the age previously assumed for the terrace ages (Gath, 1997).

Figure 1
Sample location for LG7 in Qt2 sediments, Santa Ana River, Puente Hills.

SANTA ANA MOUNTAINS

The SAM are the dominant topographic feature of Orange County. Although rising to a height of over 1700 meters, a tectonic origin of the SAM is still elusive. Cored by Peninsular Ranges batholithic rocks, the SAM are mantled by a nearly complete suite of sedimentary rocks from the Cretaceous to the Pleistocene. The SAM are terminated by the right-lateral Elsinore fault on the east, and Loma Ridge on the west. GPS velocity vectors show the Santa Ana Mountains block moving northwesterly at about 0.75 mm/yr, approximately 50% of the rate of the Perris Block, east across the Elsinore fault.

Figure 2
Qt2 in Santiago Creek elevated above Irvine Lake, Santa Ana Mountains in back.

Four fill and several strath terraces were mapped within the Santa Ana Mountains (see companion report). OSL dating of the fill terraces is underway, and preliminary results (samples LG1, LG2 and LG3 in Table 1) indicate that the surface of the second elevated terrace Qt2 at 860 feet is approximately 50 ka. Assuming that the relative, high-stand, base level for Santiago Creek has not changed significantly in that time period, this would indicate an uplift of 21 meters in 50 ka, or approx. 0.4 m/ka. OSL samples have been collected from other SAM terraces but results are still pending.

WORKING HYPOTHESES: Neotectonic Development Of Orange County

A preliminary neotectonic model to describe the geomorphic development of Orange County is shown in Figure 3 and presented in outline form below. We emphasize that <u>this is a preliminary model that may be revised significantly prior to publication</u>

1. The Santa Ana Mountains became emergent about 4 Ma, and are uplifting at a rate of approximately 0.4 mm/yr.
2. The Santa Ana Mountains are moving northwest at least 0.75 mm/yr along the Elsinore fault. However, this GPS rate captures only a small fraction of the 5-6 mm/yr slip rate on the Elsinore fault.
3. Loma Ridge became emergent approximately 2.5 Ma and has acted to block all of the northern Santa Ana Mtns drainages from directly reaching the ocean.
4. Loma Ridge is anticlinally deforming Tertiary through Quaternary sediments.
5. Loma Ridge is a southwest vergent structure that is obliquely accommodating north-south crustal shortening.
6. The internal SAM drainages have collected to form Santiago Creek, a NW-flowing river that is deflected 2.4 km northward along each of four probable hanging wall tear faults that laterally accommodate the oblique compressional component.
7. In the Pliocene to mid-Quaternary, the Newport-Inglewood fault (NIF) terminated into a right-stepping horsetail splay (Christianitos, Mission Viejo, Dana Cove faults, not shown on Figure 3) , transferring strain northward into the Capistrano Embayment graben and compressing the embayment sediments against the Santa Ana Mountains into generating the Loma Ridge anticline.
8. In the mid-Quaternary the NIF stepped westward onto the "Northern NIF" trace, resulting in the compressional step that formed the San Joaquin Hills.
9. The SJH are an anticlinally deformed structure, possibly bounded (terminated) on the east by the Dana Cove fault.
10. The SJH are north vergent, driven by strain partitioning off of the Newport-Inglewood fault.
11. The SJH became emergent less than 1Ma, and is currently uplifting at 0.25 mm/yr. The emergence age and pre-200 ka uplift rate are not constrained.
12. The Puente Hills became emergent approximately 500-700 ka, generated by uplift along the Puente Hills blind thrust at a rate of 0.4 – 0.7 mm/yr.
13. The PHBTF is accommodating the N-S compressional strain, while the right-lateral Whittier fault is accommodating the N-W vergent strain of the Elsinore fault.

14. The Whittier fault is accommodating 2-3 mm/yr of the Elsinore fault's 5-6 mm/yr strain.
15. The Coyote Hills are an en-echelon series of hanging wall folds similar to Loma Ridge. They are possibly a result of the thrusting of the Santa Ana Mountains block into the Santa Ana River basin sediments.
16. The Chino fault is the northernmost, right-stepping extension of the Elsinore fault. It is a right-lateral fault accommodating 1-2 mm/yr of the Elsinore fault's 5-6 mm/yr strain.
17. Subtracting the Whittier and Chino fault strain rates from the Elsinore fault results in a strain surplus of 1-3 mm/yr that is being accommodated in uplift of the Santa Ana Mountains.
18. The Peralta Hills fault is a backthrust off of the Elsinore fault that has deflected the Santa Ana River over 3 km westward.

Seismic Hazard Implications

1. The seismic hazard of the San Joaquin Hills fault is significantly reduced from mid-Quaternary levels, but it is still an active fault as demonstrated by the Grant et al. (2002), and the strain rate of the Grant et al., 1999 paper is still valid because it is reflective of the post-200 ka uplift rates.
2. The Loma Ridge faults shown on Figure 3 are probably inactive since the straightening of the NIF fault south of the SJH.
3. The Whittier and Puente Hills faults are significant seismic hazards that remain essentially unchanged from prior work.
4. The Chino fault is accommodating at least 1 mm/yr of right lateral strain.
5. The Santa Ana Mountains are accommodating 1-3 mm/yr of Elsinore fault strain, transferring it into uplift. The southerly extent of the SAM fault is undefined, but extends as far south as San Juan Creek.

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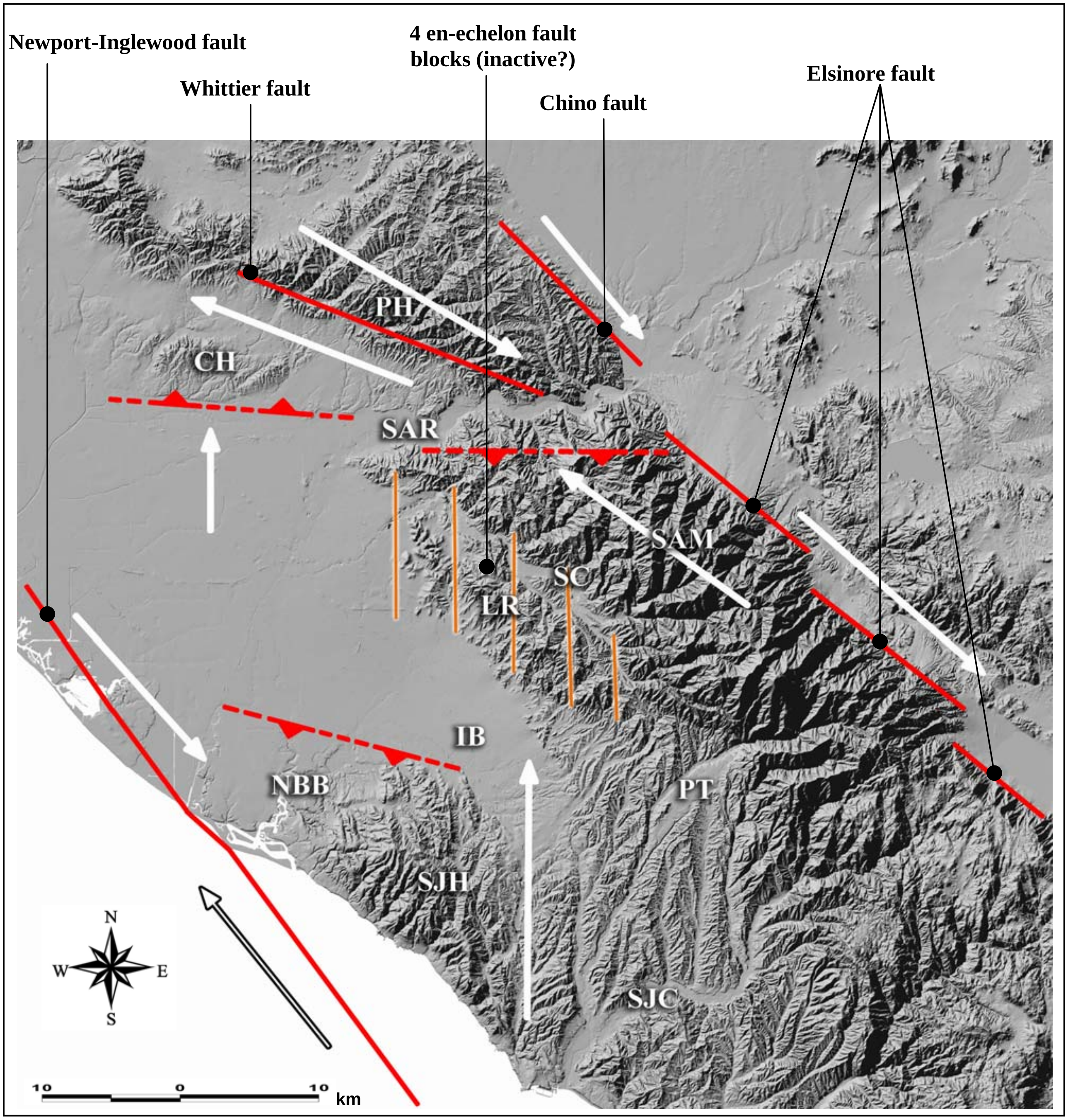

Figure 3. Preliminary neotectonic model: Proposed neotectonic model of the northern Santa Ana Mountains and southern Los Angeles basin, Orange County, California. In this model, partitioned strain off the Newport-Inglewood fault causes uplift of the San Joaquin Hills (SJH). An underlying blind thrust fault (see Shaw and Shearer, 1999) causes uplift of the Puente Hills (PH) and Coyote Hills (CH). The SAM uplift is caused by a partial termination of the Elsinore fault and consumption of slip along a north-vergent blind thrust aligned roughly east-west. The Loma Ridge (LR) uplift is caused by north-vergent strain that is compressing the Tertiary sediments against the uplifting SAM, forming Loma Ridge and deforming Santiago Creek (SC) trapped between them. Arrows indicate direction of motion. Solid red lines are previously mapped strike-slip faults. Dashed red lines are suspected blind thrust faults. Santiago Creek appears to be displaced by a series of en-echelon faults, indicated by five orange lines.

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Non-technical summary

The main objective of this research is to better understand seismic hazard in Orange County, California, an area of nearly 3 million people. This project investigates possible tectonic deformation and earthquake potential associated with undiscovered faults in or near the Santa Ana Mountains and Puente Hills by examining the patterns carved by streams. The Santa Ana Mountains are prominent features in the landscape of the metropolitan Los Angeles basin. Comparable sized mountains and foothills in surrounding areas are known to be associated with active faults. Preliminary results indicate that the mountains are rising and may contain active faults.

Availability of data

Some of the DEM data and geomorphic analysis is posted on the web at http://geolab.seweb.uci.edu/. URLs for private pages with more results can be obtained by contacting project P.I. Lisa Grant (lgrant@uci.edu), or Ph.D. student Eldon Gath (gath@earthconsultants.comT). Project data will be archived in Gath's Ph.D. dissertation, which will become available through the UCI libraries.

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